# Scouting Methods for Detection of Thrips (Thysanoptera: Thripidae) on Dendrobium Orchids in Hawaii

ROBERT G. HOLLINGSWORTH,[1] KELVIN T. SEWAKE,[2] AND JOHN W. ARMSTRONG

U.S. Pacific Basin Agricultural Research Center, USDA–ARS, P.O. Box 4459, Hilo, HI 96720

Environ. Entomol. 31(3): 523–532 (2002)

**ABSTRACT** Thrips are important pests of dendrobium orchid flowers in Hawaii primarily because of the risk that exported flowers found to be infested will be rejected by quarantine inspectors. Using nondestructive sampling, the population dynamics of thrips infesting dendrobium orchids was monitored at two farms on the Island of Hawaii over a period of 1 yr. Average thrips populations varied between 0 and 1.0 thrips per spray (flower spike). At both sites, adult thrips almost always outnumbered nymphs. The western flower thrips, *Frankliniella occidentalis* (Pergande), was the predominant species found. Using randomization tests, adult thrips were found to be randomly distributed on orchid sprays. The binomial probability distribution was used to graphically describe the accuracy of scouting results as a function of sample size and the proportion of thrips-infested flowers. Efficient methods for counting adult thrips included nondestructive field counts (direct observation), flower shakes, and extractions via Berlese funnels.

**KEY WORDS** *Frankliniella occidentalis*, thrips, scouting methods, dendrobium orchids

DENDROBIUM ORCHIDS ARE one of the most important cut flower exports grown in Hawaii. In 1997 (the most current year for which data are available), ≈4.5 million sprays (flower spikes) of dendrobium orchids were sold with a total value of over $2.5 million from a production area (shade house or greenhouse) of only 32.6 ha (Hawaii Agricultural Statistics Service 1999).

The majority of cut dendrobiums produced in Hawaii are exported to the continental United States. Dendrobium exporters must send flowers that are free of quarantine pests. Most exporters in Hawaii ship their flowers following self-inspection for pests under a program administered by the USDA Animal and Plant Health Inspection Service (Ed Uyeda, personal communication, APHIS Port Director for Hilo, HI, October 2000). Growers qualify for self-inspection by demonstrating to quarantine officials that they can consistently produce a pest-free commodity for a period of 6 mo. Quarantine inspectors at the point of destination can reject and send back or destroy flower shipments if they find pests.

The most common thrips species infesting orchid blossoms in Hawaii is western flower thrips, *Frankliniella occidentalis* (Pergande) (Hata et al. 1993, Hara and Hata 1999). The western flower thrips is not considered a quarantine pest because it is distributed throughout the United States. Conversely, the melon thrips *Thrips palmi* Karny, which is also a pest of orchid blossoms in Hawaii (Hata et al. 1991, 1993), is a quarantine species because it is found only in Hawaii and Florida (Hata et al. 1993, Castineiras et al. 1997). Quarantine inspectors generally reject shipments of flowers infested with thrips of any species, as it is impractical to find and identify all of the individuals that might be present in a consignment.

A recent survey of orchid growers showed that thrips were considered to be the most serious insect pest of cut orchids; growers used an average of 35.6 pesticide applications per year; about one-half of growers applied insecticides on a calendar basis; and that growers who based their pesticide use on scouting results made 45% fewer applications of insecticides (Hollingsworth et al. 2000). This suggests that many growers are applying pesticides unnecessarily either because they are unwilling to scout, or because they lack confidence in scouting methods. The material costs of pesticide applications are low in comparison to crop value, which averaged $78,084 per ha in 1997 (Hawaii Agricultural Statistics Service 1999). Nevertheless, growers may benefit from omitting unnecessary pesticide sprays because pesticide applications may disrupt normal harvesting schedules, cause secondary pest outbreaks (e.g., whiteflies), and require significant labor inputs.

No detailed methods have been devised for scouting thrips in orchids. Growers have been encouraged to use Berlese funnels as a monitoring tool, extracting thrips from 50–100 blossoms at a time (Tenbrink et al. 1998). This method was recommended because it is

[1] E-mail: rholling@pbarc.ars.usda.gov.
[2] University of Hawaii at Manoa, Cooperative Extension Service, 875 Komohana Street, Hilo, HI 96720.

difficult to inspect dendrobium orchids for thrips without destroying the flowers. Thrips are generally found deep within the blossoms. Sometimes thrips settle behind the pollenia, where they cannot be seen. To devise good scouting methods, it is necessary to determine both the efficiency of the scouting method, and how thrips infesting orchids are typically distributed within the crop (Shipp and Zariffa 1991). This information will determine the number and arrangement of samples that must be collected to either detect thrips (at a given level of probability) or estimate their population densities. Our objectives were to describe the distribution of thrips in commercial orchid plantings, and test for spatial dependencies in samples collected close together; describe the relationship between sample size and the probability of thrips detection, and the relationship between sample size and the accuracy of estimates for the proportion of infested flower sprays; and to compare the efficiencies of three sampling methods (nondestructive field counts, flower shakes and Berlese funnels) as monitoring tools for thrips in orchids.

## Materials and Methods

Studies were carried out at two commercial dendrobium orchid farms on the island of Hawaii, one located in Kailua-Kona and the other located in Kea'au. The Kailua-Kona farm consisted of a 1.13-ha shadehouse (30–40% shade) at 60 m elevation in a relatively dry area (38 cm per year average rainfall). The farm had a history of thrips problems. Plants were grown in a coarse cinder medium and irrigated by overhead sprinklers ≈3–5 times per week. Planting density was 8.5–10.0 plants per square meter, and the orchid canes averaged ≈1.2 m in height. Orchid beds were 1.2 m wide, with 1.5-m aisles. The grower applied insecticides as needed to control thrips, aphids, blossom midge (*Contarinia maculipennis* Felt), and red and black flat mites [*Brevipalpus phoenicis* (Geijskes)] using a self-propelled mist sprayer that delivered 75 psi (517 kPa) at nozzle tips. Spray applications are indicated in Fig. 1. Other crops planted nearby (within 0.5 km) that may have served as sources for immigrant thrips included dendrobium orchids, plumeria, (*Plumeria rubra* L.), mango (*Mangifera indica* L.) and fountain grass [*Pennisetum setaceum* (Forsskal) Chiov.].

The Kea'au farm consisted of a 0.60-ha planting at 122 m elevation under plastic roof material (≈20% shade) with open sides in a relatively wet area (356 cm per year average rainfall). Thrips were seldom a problem on this farm. Orchids were grown in coarse cinder and irrigated about two times per week by hand or via sprinklers located below the plant canopy. Planting density was 12.4 plants per square meter and orchid canes averaged ≈2.4 m in height. Orchid beds were 1.0 m wide with aisles of 1.2 m. Plants were sprayed with insecticides as needed for control of thrips and blossom midges using a pressure sprayer (180 psi or 1,241 kPa). In some cases, spot spray applications were made with a back-pack sprayer. Spray applications are indicated in Fig. 2. No other plantings were noted in the immediate area (within 0.5 km) that might have served as sources for immigrant thrips.

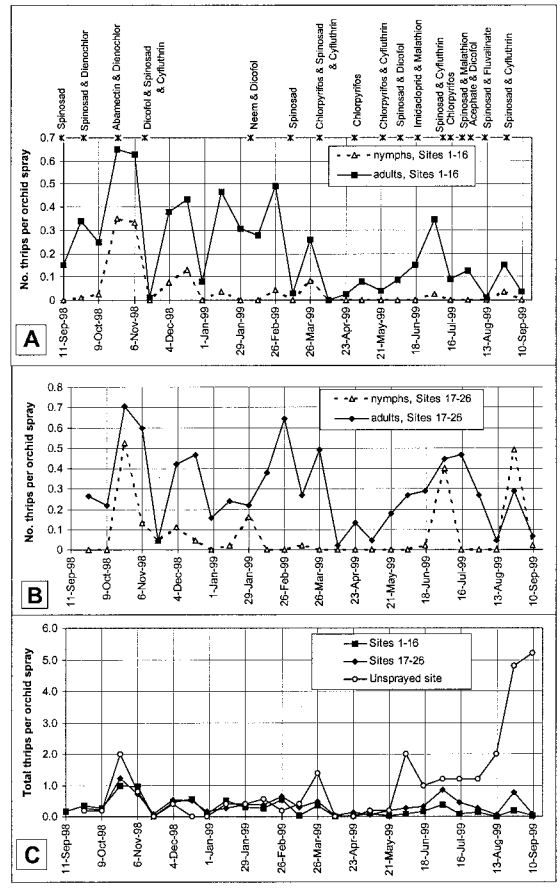


**Fig. 1.** Number of thrips per orchid spray at the Kona farm: (A) from within the intensively sampled area; (B) at nine representative sites outside of this area; (C) from an unsprayed area of the shadehouse, in comparison with the two previous areas (counts represent nymphs plus adults). Data were collected via nondestructive field counts. Timing of pesticide applications are indicated along upper edge of first figure.

At both farms, thrips abundance was monitored by intensive sampling carried out every 2 wk. Sampling consisted of nondestructive counts of adult thrips and nymphs on flower sprays. The column of each flower blossom was gently pulled aside to permit viewing into the interior of the flower. We also looked for thrips between overlapping petals. Intensive sampling was carried out along four alternate rows, each 29 m long, comprising an area of 0.05 ha at the Kona farm and 0.04 ha at the Kea'au farm. Each row was divided into four equal sections or sampling sites, and five orchid sprays (or as many as were available) at harvest maturity were sampled from each section. Each spray had at least four open blossoms. Flowers were less numerous

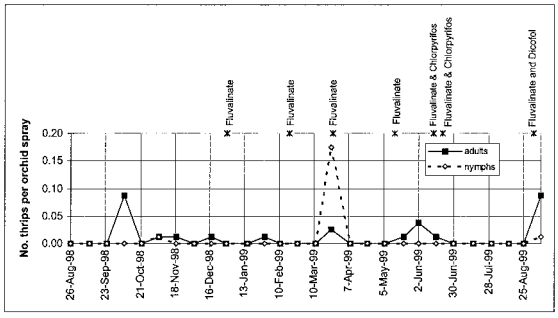


**Fig. 2.** Number of thrips per orchid spray in the intensively sampled area at the Kea'au site. Data were collected via nondestructive field counts. Timing of pesticide applications indicated along upper edge of graph.

at the Kona farm, and the number of flower sprays available at each sampling site was sometimes less than five.

At the Kea'au farm, thrips were counted on the variety UH 306, which was the only variety grown on this farm. At the Kona farm, the intensively sampled area was planted in white dendrobium orchids (a mixture of UH K800 and UH 306, two similar varieties developed by the University of Hawaii). For comparison, we also sampled orchids from 10 additional sites (five orchid sprays per site) chosen throughout the remaining areas of the shadehouse. These 10 sites included a mixture of varieties and flower colors [UH 232 (lavender); UH 503/507 (dark purple); UH 1041 (white/purple); UH 306 (white); UH K800 (white); Myron Mooney (white); and Uniwai Blush (whitish-pink)]. The sampling site planted to UH 1041 was located in a corner of the shadehouse comprising six plant rows or 0.04 ha, that was left unsprayed between 7 February and 24 July 1999.

To determine which species of thrips were present in the orchids, thrips were collected opportunistically a various intervals during the year-long study using an aspirator and by using Berlese funnels (Tenbrink et al. 1998), consisting of a 10-inch funnel positioned below a brooder lamp with a 40-W incandescent bulb. Metal straps held the lamp ≈1.5 cm above the funnel preventing over-heating of the sample. Alcohol (30%) was used in the collecting jar beneath the funnel; flower sprays were left in funnels until dry (≈2 d). The collected thrips were mounted in Hoyer's mounting medium on glass slides and identified with the aid of phase-contrast microscopy using keys from Mound and Kibby (1998). Sub-samples of thrips mounted on slides were submitted to the Agricultural Diagnostic Service Center (University of Hawaii at Manoa) for confirmation of identity. Slide mounts of *F. occidentalis* collected from the Kona site were deposited as voucher specimens K1-K6 in the Entomology Collection of the University of Hawaii at Manoa (Honolulu).

In separate tests, we compared three sampling methods for efficiency in collecting adult thrips and nymphs. The three methods were nondestructive field counts, Berlese funnels, and a 5-s shake of flowers into a clear, plastic bag (30 by 40 cm) (flowers shaken individually). Efficiency was determined by comparison with an absolute sampling method, which involved collecting orchid sprays individually into self-sealing plastic bags (30 by 40 cm), freezing them for ≥24 h, then counting thrips while dissecting blossoms under a microscope. Flowers used in these studies were either naturally infested (collected in the field) or infested within 18.9-L buckets, 9 d before use, using a laboratory colony of western flower thrips reared on green beans and pollen. Details about each test are found in table footnotes.

To determine if counts of adult thrips in adjacent sampling sites were correlated, the data were subjected to a Monte Carlo test involving a nearest neighbor statistic (Manly 1997, p. 69). Data used were from the intensively sampled area at Kona site. Nymphs were not used in this analysis because they are difficult to observe during scouting. Our nearest neighbor statistic ($\varphi$) was calculated as follows:

$$\varphi = \sum_{A=1}^{16} |X_A - X_B|,$$

where XA was the site average and XB the adjacent site average within the same plant row. If XA was situated between two adjacent sites, then |XA- XB|was calculated twice, and the values averaged. Site averages were based on five orchid sprays per site, or as many as were available. A low value of $\varphi$ indicated greater similarity among adjacent sites. Using statistical software (SAS Institute 1988), the test statistic ($\varphi$) was generated 999 times after randomizing the locations of the 16 site averages. Probability values were obtained by comparing $\varphi$ for the actual data with the 999 values of $\varphi$ obtained via randomizations. If the percentile for $\varphi$ using actual data for a particular date was ≤2.5 or >97.5, then the result was deemed "significant." When $\varphi$ for the actual data were tied with a large number (>25) of the randomly generated $\varphi$ values coincident with the 2.5 or 97.5 percentiles, the result was dropped from further analysis. A separate analysis was conducted for each date. The number of dates associated with significant test statistics was compared with the number that would be expected due to type 1 error under the null hypothesis [calculated as "number of dates" * (0.05)] to permit a qualitative assessment regarding the strength of the effect.

We used the same data set and approach to determine if counts of adult thrips on orchid sprays *within each sampling site* were more similar to one another than counts of adult thrips taken at random from orchid sprays anywhere within the intensively sampled area. For each sample date, a standard error of the mean (±SEM) was computed to measure the variation in thrips counts within each of the 16 sampling sites; the average SEM for all 16 sites constituted our test statistic. This result using actual data were compared with 999 test statistics based on a random as-

**Table 1. Species composition of thrips sampled during the study (count data)**

| Species | Kona farm | | Kea'au Farm | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| *Chaetanaphothrips orchidii* Moulton | 0 | 0 | 0 | 9 |
| *Frankliniella occidentalis* (Pergande) | 19 | 85 | 0 | 0 |
| *Frankliniella* sp. | 0 | 1 | 0 | 2 |
| *Scirtothrips mangiferae* Priesner | 0 | 1 | 0 | 0 |
| *Scirtothrips* sp. | 1 | 2 | 0 | 0 |
| *Thrips hawaiiensis* (Morgan) | 0 | 1 | 0 | 3 |
| *Thrips palmi* Karny | 1 | 5 | 0 | 0 |
| *Thrips tabaci* Lindeman | 1 | 5 | 0 | 0 |

sortment of thrips count data associated with the 80 orchid sprays.

Finally, analyses were conducted to determine whether thrips count data from a particular date were correlated with count data collected 2 wk earlier from the same sampling site. Significant correlations might indicate a low rate of thrips dispersal or suggest that plants at certain sampling sites were more attractive to thrips. Using the average number of adult thrips per orchid spray at each sampling site as the variable of interest, Spearman correlations of rank data (PROC CORR, SAS Institute 1988) were carried out for all unique pairings of 26 sample dates (data for one date was omitted as no adult thrips were counted on that date). The number of significant correlations ($P \leq 0.05$) associated with adjacent sample dates (dates 2 wk apart) was compared with the expected number based on the total number of significant correlations for all sample dates.

Graphs involving probabilities of thrips detection for given sample sizes were based on binomial probabilities for presence/absence of thrips on sprays. The binomial model was used because Monte Carlo analyses supported the assumption that infested sprays were randomly distributed in the sampled area. Confidence intervals for the true proportion of infested sprays based on sample proportions were obtained from a table of binomial confidence intervals (Steel and Torrie 1980).

## Results and Discussion

**Patterns of Infestation.** At the Kona field site, a total of 3,222 orchid sprays was examined in the field for thrips over a period of 1 yr. On average, sprays in the intensively sampled area had 8.7 open blossoms (SD = 2.82, $N = 419$). As expected, thrips were relatively common at this site, despite frequent applications of insecticides (Fig. 1). The western flower thrips, *F. occidentalis*, was the most common thrips species at this site, comprising 85% in sub-samples collected over the duration of the trial via Berlese funnels and via aspiration from flowers ($N = 122$) (Table 1). Females outnumbered males by greater than a 4–1 ratio. Onion thrips, *Thrips tabaci* Lindeman, and the melon thrips *T. palmi* Karny (the latter being a Federal-Action Quarantine Pest) each comprised ≈4% of the adult thrips collected.

In the intensively sampled area, populations of adult thrips were always greater than populations of nymphs, based on results obtained using nondestructive field counts (Fig. 1A). Over the sampling period, the average number of adults per spray ranged from 0.00–0.65, while the number of nymphs varied between 0.00 and 0.35. The relative scarcity of nymphs may have been partly due to a bias in the counting method, as small nymphs are difficult to see within flowers. Nevertheless, these data tend to support the grower's hypothesis that immigration of thrips from surrounding cropping areas made a significant contribution to the population in his shadehouse. The grower noted that his thrips problems generally increased following several days of winds from the south. Crops located to the south but within 0.5 km of the Kona site included large plantings of plumeria, a crop commonly infested by western flower thrips, the most common thrips species recovered from the Kona farm.

From 15 November to 6 February (winter), thrips populations remained at low to moderate levels (particularly nymphs), with no signs of a build-up, despite a lack of insecticide applications during this period. During this period, flower production was relatively low, and predators (such as anthocorid bugs) were rare. Therefore, it seems most probable that the low population levels were related to poor host quality, or reduced immigration of thrips from the surrounding farms.

Population trends of thrips in areas of the shadehouse outside of the intensively sampled area (except in the untreated area) mirrored those within (Fig. 1 A and B). Thus, insect counts within the intensively sampled area, which was only 0.05 ha, provided a good index of the average thrips populations over the entire 1.13-ha shadehouse. Fig. 1C compares average thrips counts (nymphs + adults) on flowers in the intensively sampled area, an unsprayed corner of the shadehouse, and the remaining areas of the shadehouse. The unsprayed corner consisted of six rows comprising ≈0.04 ha that were left unsprayed between 7 February and 24 July. Thrips populations remained low in this area for months, but increased to high levels by 3 June 1999. Even though four pesticide applications were made in this area beginning 24 July, thrips populations remained high until the end of the trial (9 September 1999), possibly because a portion of the population (pupae in the soil) was escaping treatment.

At the Kea'au farm, a total of 2,240 orchid sprays was examined in the field for thrips over a period a little greater than 1 yr. On average, sprays had 11.5 open blossoms (SD = 3.1, $N = 448$). Thrips populations at this site remained very low throughout the year of data collection (Fig. 2). Thrips were detected on 10 of the 28 sample dates, and adults out-numbered nymphs on all except one date (Fig. 2). The most common thrips species collected was *Chaetanaphothrips orchidii* Moulton, representing 64% of thrips identified from

subsamples ($N = 14$). This species is frequently found infesting anthurium, a common crop in the Puna district of Hawaii island in which this farm is located. The percentage of orchid sprays infested with nymphs and adults was 0.1 and 0.8%, respectively. This compares to 2.9 and 16.4% of orchid sprays infested with nymphs and adults, respectively, at the Kona farm. Although thrips were much more common at the Kona farm, the percentage of infested orchid sprays from which only one adult thrips was counted was similar (78.3 and 84% for the Kona and Kea'au sites, respectively). This indicates that adult thrips infesting dendrobium orchids are usually solitary over a wide range of insect densities.

Our data from the Kea'au farm shows that the occurrence and locations of thrips within the greenhouse were not predictable from one sampling date to the next. For example, thrips were detected at multiple sites on four dates (Fig. 3); for three of these dates (all except 2 June 1999), no thrips had been detected during intensive sampling 2 wk earlier. Thus, by the time thrips were detected in the crop, they were already present at multiple sites that were usually not contiguous with one another. This pattern suggests that the adult thrips found were recent immigrants. When thrips were detected either by our survey or by the grower himself, the grower usually responded by spot-spraying the infested area. The grower's apparent success in controlling thrips using this method may be partly due to other factors. Small spiders and predatory mites [identified as *Agistemus terminalis* (Quayle)] were common in orchid flowers and foliage at the Kea'au site, and these may have played a role in keeping the thrips population very low.

**Sample Distribution of Thrips on Flower Sprays, Actual Versus Random Model.** The actual sample distributions of thrips nymphs and adults on individual flower sprays was compared with sample distributions predicted by a random (Poisson) distribution model, using field count data collected from the intensively sampled areas of the Kona and Kea'au farms (Table 2). The distribution of adult thrips on flower sprays at the Kea'au farm fit the random model ($\chi^2 = 3.1$ and df = 1, critical value for chi-square at $P \leq 0.05 = 3.8$). However, distributions of nymphs at the Kea'au farm and distributions of nymphs and adults at the Kona farm did not fit the random model (Table 2). Despite this statistical lack of fit, actual distributions of adult thrips on both farms did in fact mimic the basic pattern of the random distribution model. The significant chi-square value at the Kona site associated with adult thrips occurred because the actual number of flower sprays with one adult thrips each was slightly less than the number predicted by the random model, while the number of sprays with two thrips each was slightly greater than expected. Mating attraction could explain this result. In any case, the deviation from the random model was sufficiently small as to justify the assumption that adult thrips are randomly distributed for the purpose of developing sampling plans.

**Nearest-Neighbor Analysis Involving Average Numbers of Adult Thrips Present in Adjacent Sampling Sites.** Using data from the Kona farm, it was possible to carry out a nearest-neighbor analysis for 17 of the 27 sample dates. Ten dates were eliminated either because of missing data (no orchid sprays within one or more sampling sites) or because thrips counts were very low, resulting in a large number of tied statistics which prevented an accurate assessment of significance levels. For 14 of the 17 dates, no nearest neighbor effects were detected ($P \leq 0.05$ for each date), indicating that the average numbers of adult thrips in adjacent plots were independent of one another (Table 3). Nearest neighbor effects were indicated for three of the 17 sample dates: a significantly low test statistic (percentile = 1.9), indicating similarity among nearest neighbors, occurred on 23 October 1998; significantly high test statistics (percentiles = 97.6 and 97.7) were computed for data collected 11 September and 25 September 1998, indicating a dissimilarity among nearest neighbors. Given that the nearest neighbor analysis was carried out separately for each of the 17 sample dates using an alpha level of 0.05, we would expect, under the null hypothesis, that there would be (on average) 0.85 test statistics declared significant (Table 3). In actuality, three test statistics were declared significant. Whether or not this number is significantly greater than the expected number cannot be determined, as a chi-square analysis is not appropriate when the expected value is $<5$ (Pedigo and Zeiss 1996). Regardless, these results indicate that when scouting for thrips, samples collected at least 7 m apart along a plant row will normally, if not always, provide independent information about the level of thrips present in a particular area of the shadehouse.

**Variation of Adult Thrips on Individual Sprays within Sampling Sites.** Of the 27 sample dates, valid data were available for 20 dates. Seven dates were eliminated because of a large number of tied statistics that prevented an accurate assessment of significance levels. On 19 of the 20 sample dates, the variation in the number of adult thrips on flower sprays in the intensively sampled area was independent of sampling site, indicating a random distribution of thrips on orchid sprays. A significant test statistic occurred on only one date (12 February 1999; percentile = 0.1%). Under the null hypothesis, we would expect an average of one test statistic to be deemed significant, given that 20 separate analyses were carried out (one per sample date), each with an alpha level of 0.05 (Table 3). Therefore there is no indication that counts of adult thrips within sampling sites were more similar to one another than counts taken from anywhere else within the overall sampling area. The practical importance of this result is that each orchid spray provided independent information about the level of thrips present in the orchid planting. While it is, of course, advisable for growers to sample orchid sprays representatively from the entire cropping area of interest, it would appear that even samples collected adjacent to one another do not bias results to a measurable degree.

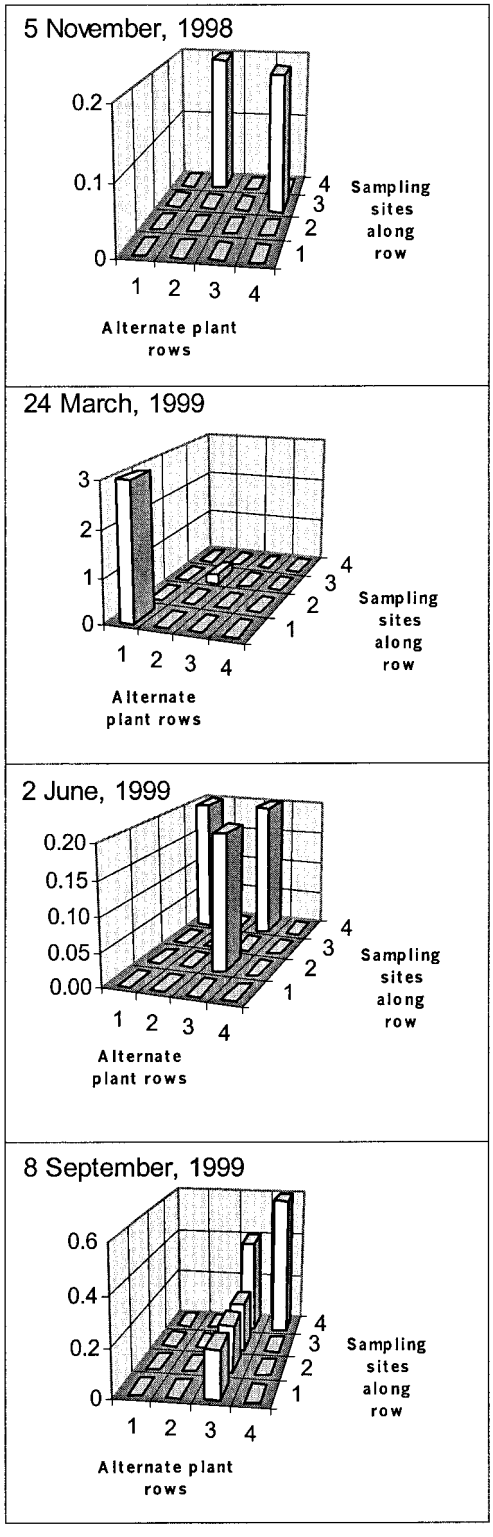


Fig. 3. Distributions of thrips at early stages of infestation at the site in Kea'au. Height of bars represent average numbers of thrips (nymphs plus adults) per orchid spray ($N = 5$ sprays).

**Correlation of Count Data Between Sample Dates.** Among all unique pairings of adjacent sample dates, there were no significant correlations ($P \leq 0.05$) associated with average counts of adult thrips made at each of the 16 sampling locations in the intensively sampled area (Table 3). Thus, we found no evidence that adult thrips persisted in particular sampling areas during the 2-wk interval between samplings. Count data for nymphs were not used for correlation analysis because counts were too low for a good analysis (e.g., no nymphs were found in 16 of the 27 sample dates). These results provide further evidence that the particular choice of sampling area within the shade house is not likely to bias the estimate for the average level of thrips, particularly if a reasonable effort is made to collect samples representatively from the varieties of orchids present.

**Comparison of Flower "Shakes," Nondestructive Field Counts and Berlese Funnels as Sampling Tools for Thrips.** The efficiencies of three different methods for sampling thrips were compared in one field experiment and several laboratory experiments. A 5-s flower shake dislodged 48–93% of the adult thrips from blossoms, but only 4–22% of the nymphs (Table 4). Similarly, direct counting of thrips in the field had a greater efficiency for adults in comparison to nymphs (79 and 14%, respectively; Table 4). Berlese funnels were slightly less efficient (34–59%) for adult thrips than the other two methods, but appeared to be as good or better for sampling nymphs, with efficiencies ranging from 14 to 17% (Table 4).

Flower shakes have been recommended as a sampling method for western flower thrips in a number of crops. Terry and DeGrandi-Hoffman (1988) found that a 9-s and 6-s shake removed 84 and 74%, respectively, of the total number of western flower thrips from apple blossom clusters; whereas a 3-s shake removed only 53% of thrips and produced variable results. Frank and Huber (1987) used a sharp "tap" with a pencil to dislodge western flower thrips from blossoms of pistachios, copying a method used successfully to sample onion thrips on potato (Powell and Landis 1965). On orchids, the shake method was found to be simpler and faster than counting thrips directly on flowers or using Berlese funnels to extract thrips. However, care must be taken not to shake flowers too vigorously, as flowers or petioles may otherwise become bruised, and shelf life could be reduced. For our research, flowers were shaken into clear plastic bags, which could then be sealed and taken back to the laboratory for careful counting of collected thrips. Growers who wish to use the flower shake method might find it more convenient to shake flowers into a large white plastic container, such as a 18.9-L bucket. Against such a background, a person with good eyesight could easily spot adult thrips and larger nymphs.

Direct counting of thrips in orchid flowers (nondestructive field counts) is a useful method for monitoring changes in thrips populations over time because a large number of flowers can be examined without damaging the crop or affecting insect populations. The disadvantage of this method is that it is

**Table 2. Sample distribution of thrips on orchid sprays in relation to sampling distribution as predicted by Poisson (random) distribution**

| Farm | Thrips per spray | No. of sprays with given no. of thrips | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nymphs | | | Adults | | |
| | | Obs | Pred | $\chi^2$ | Obs | Pred | $\chi^2$ |
| Kona | 0 | 1,901 | 1,901.8 | 0.0 | 1,636 | 1,590.5 | 1.3 |
| | 1 | 37 | 55.4 | 6.1 | 252 | 330.6 | 18.7 |
| | 2 | 14 | 0.8 | NC | 59 | 34.4 | 17.7 |
| | 3 | 5 | 0.0 | NC | 8 | 2.4 | NC |
| | Total $\chi^2$ | | | 6.1[a] | | | 37.7[b] |
| Kea'au | 0 | 2,237 | 2,224.1 | 0.1 | 2,221 | 2,215.1 | 0.0 |
| | 1 | 2 | 15.9 | 12.1 | 16 | 24.7 | 3.1 |
| | 2 | 0 | 0.1 | NC | 1 | 0.1 | NC |
| | 3 | 0 | 0.0 | NC | 1 | 0.0 | NC |
| | Total $\chi^2$ | | | 12.2[a] | | | 3.1[a] |

Data were collected using non-destructive field counts in the intensively sampled areas of the Kona and Kea'au farms. Obs, observed value. Pred, predicted value based on Poisson distribution, as described in Pedigo and Zeiss 1996. NC, not computed, because expected cell value <5 (Pedigo and Zeiss 1996).

[a] Chi-square critical value ($P = 0.05$, df = 1) = 3.8.

[b] Chi-square critical value ($P = 0.05$, df = 2) = 6.0.

slow (30 s to 1 min per flower spray), requires good eyesight, and requires the person counting to quickly distinguish between thrips and other insects that are commonly present in blossoms (wasp parasitoids, gnats, aphids, and anthocorid bugs). Most growers will find the use of Berlese funnels to be more practical than direct counting of thrips on flowers as a method for tracking insect populations. When funnels are used, thrips are collected into alcohol, permitting microscopic examination and species identification. Species identification is critical when trying to determine why pesticides may have failed, or for determining the most likely sources of immigrant populations. The main disadvantages of the Berlese funnel method are that it requires special equipment, and a dry-down period for the flowers placed into the funnel (usually 24 h). In our tests, efficiencies of collection using Berlese funnels ranged from 34 to 59% for adults and from 14 to 17% for nymphs. In a preliminary test, Hata et al. (1993) found no difference in the number of collected thrips using either Berlese funnels for extraction or microscopic examination of dissected blossoms. However, in their study, they apparently sampled only a small number of field-collected orchid sprays ($t$-test and df = 6), and it is possible that they obtained similar results using these two methods as an artifact of background variation.

**Sample Sizes Needed for Thrips Detection and Estimation of Thrips Population.** Growers who use a scouting program for thrips need to know how many samples must be collected, either for thrips detection, or to estimate thrips population levels. Given our find-

**Table 3. Comparison of the actual versus predicted number of significant test statistics associated with spatial and temporal effects on counts of adult thrips on orchid sprays (Kona farm)**

| | Effects | | |
|---|---|---|---|
| | Similar counts among adjacent sampling sites[a] | Similar counts within sampling sites[b] | Similar counts on adjacent sample dates[c] |
| No. test statistics declared significant ($P \leq 0.05$) | 3[d] | 1[d] | 2 |
| Expected no. | 0.85[e] | 1.00[e] | 0.74[f] |
| Total no. test statistics | 17[g] | 20[g] | 24 |

[a] For each sample date, the sum of the differences in the average number of thrips at neighboring sites was compared using actual versus randomized data.

[b] For each sample date, the sum of SEM calculations for counts of thrips on orchid sprays within each sampling site was compared using actual versus randomized data.

[c] Similarity was determined by comparing the number of significant correlations (of average count data from each sampling site) associated with adjacent sampling dates with the number of correlations expected to be declared "significant" under the null hypothesis.

[d] A "significant" result occurred if the percentile of the test statistic for the actual data was ≤2.5 or >97.5 in comparison to 999 test statistics computed using randomized data.

[e] Expected number (based on the null hypothesis) representing type I error was calculated as ["number of sample dates" * (0.05)] as 0.05 was the alpha level used in the analysis for each date.

[f] The number of significant correlations *expected* (under the null hypothesis) out of a sample size of 24 pairings of adjacent sample dates was based upon the number of significant correlations (10) and non-significant correlations (315) which resulted from all unique correlations of 26 sample dates [Expected no. = 24 * (10/325)]. Data for one of the original 27 sample dates was omitted as all thrips counts were zero.

[g] Although 27 test statistics were computed (one for each sample date), some were omitted because of missing data, or because actual results were tied with a large number of the randomly generated statistics.

**Table 4. Average number of thrips per orchid spray and sampling efficiencies associated with three methods for counting thrips infesting orchid flowers**

| Method | No. nymphs (±SEM) | % Efficiency[a] | No. adults (±SEM) | % Efficiency |
|---|---|---|---|---|
| Experiment 1[b] | | | | |
| Field counts[c] | 1.0b (0.4) | 13.7 | 1.1a (0.3) | 78.6 |
| Flower shake[d] | 0.3b (0.2) | 4.1 | 1.3a (0.6) | 92.9 |
| Flower dissection[e] | 7.3a (1.7) | | 1.4a (0.5) | |
| Experiment 2[f] | | | | |
| Test 1 | | | | |
| Flower shake | 9.1a (4.0)[g] | 22.3 | 3.1a (1.5)[g] | 47.7 |
| Flower dissection | 40.9b (7.2) | | 6.5a (1.8) | |
| Test 2 | | | | |
| Berlese funnel (Rep 1)[h] | 12.5a (2.9) | 16.9 | 1.9a (0.5) | 34.1 |
| Flower dissection | 74.1b (16.9) | | 5.5b (1.5) | |
| Test 3 | | | | |
| Berlese funnel (Rep 2) | 3.4a (0.6) | 14.0 | 2.1a (0.4) | 58.6 |
| Flower dissection | 24.1b (4.3) | | 3.6a (5.1) | |

Within a column and for each test or experiment separately, numbers followed by different letters are significantly different ($P \leq 0.05$).

[a] Efficiency calculations based on results using an equal number of orchid sprays from the same source that were dissected.

[b] Data were gathered from 21 naturally infested orchid sprays (seven per treatment, with flower location within plant row as a blocking factor). Rank data were analyzed using a distribution-free multiple comparison test based on Friedman Rank Sums for two-way layout (Hollander and Wolfe 1973, p. 151).

[c] Thrips counted non-destructively via examination of orchid sprays in the field.

[d] Flower sprays were shaken individually for 5 seconds within a clear plastic bag (30 × 40 cm). Bags were examined under a dissecting microscope and living thrips were counted.

[e] Flower sprays were frozen to kill thrips, and dissected under a microscope.

[f] Orchid sprays (eight for each average presented) were artificially infested with western flower thrips adults 9 days before extractions. Data were analyzed using *T*-test with Satterthwaite's approximation for unequal variances (SAS Institute Inc. 1988).

[g] Thrips collected in the bag via shaking plus those recovered via dissection of the same flower after it was frozen was an average (per spray) of 57.3 and 6.3 for nymphs and adults, respectively.

[h] Funnel constructed according to Tenbrink et al. (1998), with a gap between the hood containing the light and the funnel.

ing that adult thrips were randomly distributed on orchid sprays, the probability of detecting thrips is a binomially distributed variable, and can be computed as 1- [probability of finding no thrips on *N* sprays] = 1-[(proportion of "uninfested" sprays) $^{N}$] ("uninfested" as determined by whatever sampling method is being deployed). The functional relationship shown in Fig. 4 is independent of the sampling method employed, although the data plotted were derived from field counts at the Kona site. Note that when only five orchid sprays are examined, the probability of detection will be ≥95% only when the proportion of infested sprays is at least 0.45. However, if 20 sprays are examined for adult thrips, the probability of detection will be ≥95% whenever the proportion of infested sprays is ≥0.14 (Fig. 4). The relationship shown in Fig. 4 would also hold true for thrips nymphs, assuming orchid sprays infested with nymphs were randomly distributed in the crop. However, our data were not sufficient for examining the distributions of nymphs.

Growers with chronic thrips problems may be less interested in detection than they are in estimating the

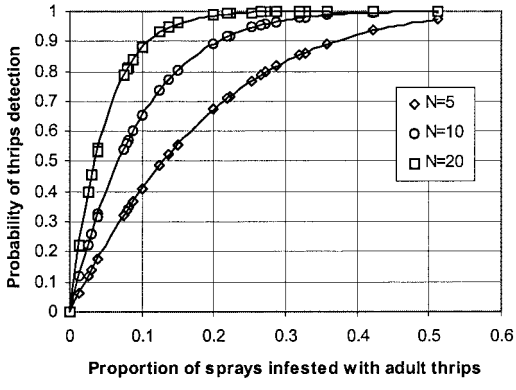


**Fig. 4.** Probability of detecting adult thrips as a function of the number of orchid sprays sampled (N) and the proportion of orchid sprays "infested" (as determined by the particular sampling method employed). Probabilities were computed as 1 − [probability of finding no thrips on *N* sprays] = 1 − [(proportion of uninfested sprays)$^{N}$] (binomial sampling distribution).

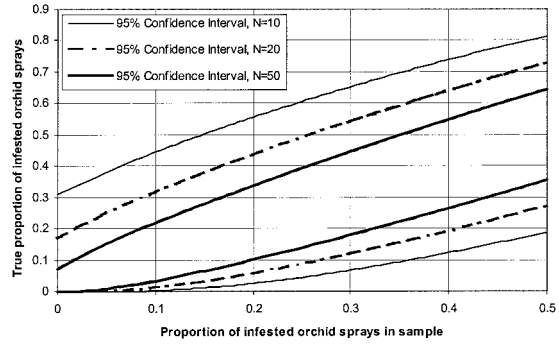


**Fig. 5.** True proportion of infested orchid sprays as a function of proportion of infested orchid sprays in sample, based on the binomial sampling distribution.

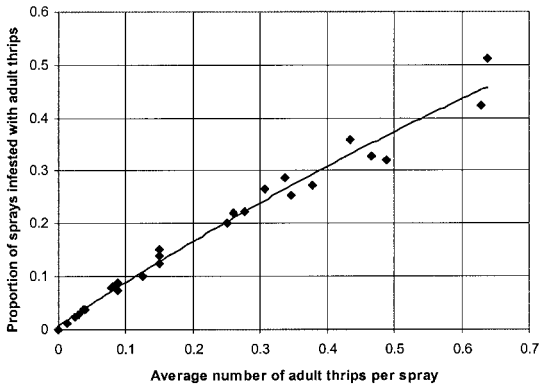


**Fig. 6.** Proportion of sprays infested with thrips adults versus average number of thrips per spray. Each point is based on field counts using 80 orchid sprays examined on different dates within the intensively sampled area of the Kona farm.

level of the thrips population, to time insecticide applications with population increases. Fig. 5 shows the relationship between the true proportion of infested orchid sprays and the proportion of infested orchid sprays determined by sampling 10, 20, or 50 sprays. For example, if 10% of orchid sprays are infested in a sample of 50, then the true proportion of infested sprays in the shadehouse or greenhouse is calculated to be between 0.03 and 0.21 at the 95% probability level. Given the wide range for the true infestation level associated with even large samples, growers interested in monitoring thrips would benefit greatly by using a rapid sampling method, such as flower shakes. Those scouting for thrips may find it inconvenient to count thrips separately from each spray. An estimate for the proportion of sprays infested with adult thrips can be easily derived from the total number of adult thrips collected in a sample of a given size, using the relationship shown in Fig. 6. For practical purposes, one can estimate the proportion of sprays infested with adult thrips simply by dividing the total number of adult thrips collected by the number of orchid sprays sampled.

Regardless of the sampling method used, a grower with a production area $\geq$0.5 ha could presumably justify investing several hours of labor per week scouting for thrips and other pests in the crop. Scouting facilitates better timing of insecticide applications, an important consideration given that thrips are difficult to bring under control once populations have reached high levels. Growers who normally follow a calendar-based spray will benefit from scouting if they discover that insecticide applications are not necessary at certain times of the year. A survey conducted among growers of cut orchids showed that growers who based their pesticide-use decisions on the results of scouting for pests made 45% fewer applications of pesticide products compared with those who followed a calendar approach (Hollingsworth et al. 2000). This suggests that some growers may be applying insecticides unnecessarily, incurring additional costs for labor and materials, and increasing the risk that secondary pests (such as aphids and whiteflies), normally held in check by natural enemies, will become a problem.

## Acknowledgments

We thank Paul Barr (USDA-ARS) for writing the statistical programs used in the randomization tests; Steven Peck (Brigham Young University), Arnold H. Hara (University of Hawaii), and two anonymous reviewers for manuscript reviews; Lee Goff for identifying predatory mites from orchids; Brian Bushe and Dick Tsuda (University of Hawaii at Manoa) for identifying reference specimens of thrips; Jason Okamoto, John Ross, Vinnie Shishido, Mark Munekata, and Mariko Imamura for technical assistance; and Ed Linse for allowing us to carry out research on his farm.

## References Cited

**Castineiras, A., R. M. Baranowski, and H. Glenn. 1997.** Distribution of *Neoseiulus cucumeris* (Acarina: Phytoseiidae) and its Prey, *Thrips palmi* (Thysanoptera: Thripidae) within eggplants in south Florida. Fla. Entomol. 80: 211–217.

**Frank, W. A., and R. T. Huber. 1987.** Seasonal population trends and damage associated with western flower thrips, *Frankliniella occidentalis* Pergande, on Arizona pistachios. Southwest. Entomol. 12: 299–303.

**Hara, A. H., and T. Y. Hata. 1999.** Pests and Pest Management, pp. 29–45. *In* K. Leonhardt and K. Sewake (eds.), Growing dendrobium orchids in Hawaii: production and management guide. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI.

**Hata, T. Y., A. H. Hara, and J. D. Hanson. 1991.** Feeding preference of melon thrips on orchids in Hawaii. HortScience 26: 1294–1295.

**Hata, T. Y., A. H. Hara, B.K.S. Hu, R. T. Kaneko, and V. L. Tenbrink. 1993.** Field sprays and insecticidal dips after harvest for pest management of *Frankliniella occidentalis* and *Thrips palmi* (Thysanoptera: Thripidae) on orchids. J. Econ. Entomol. 86: 1483–1489.

**Hawaii Agricultural Statistics Service. 1999.** Statistics of Hawaii Agriculture 1997. Agricultural Development Division, Hawaii Department of Agriculture, Honolulu, HI.

**Hollander, M., and D. A. Wolfe. 1973.** Nonparametric statistical methods. Wiley, New York.

**Hollingsworth, R. G., A. H. Hara, and K. T. Sewake. 2000.** Pesticide use and grower perceptions of pest problems on ornamental crops in Hawaii. J. Ext. 38(1) (http://joe.org/joe/2000february/rb1.html).

**Manly, B.F.J. 1997.** Randomization, bootstrap and Monte Carlo methods in biology, 2nd ed. Chapman & Hall, London.

**Mound, L. A., and G. Kibby. 1998.** Thysanoptera, an identification guide, 2nd ed. CAB, New York.

**Pedigo, L. P., and M. R. Zeiss. 1996.** Analyses in insect ecology and management. Iowa State University Press, Ames, IA.

**Powell, D. M., and B. J. Landis. 1965.** A comparison of two sampling methods for estimating population trends of thrips and mites on potatoes. J. Econ. Entomol. 58: 1141–1144.

**SAS Institute. 1988.** SAS/STAT user's guide, release 6.03. SAS Institute, Cary, NC.

**Shipp, J. L., and N. Zariffa. 1991.** Spatial patterns of and sampling methods for western flower thrips (Thysanoptera: Thripidae) on greenhouse sweet pepper. Can. Entomol. 123: 989–1000.

**Steel, R.G.D., and J. H. Torrie. 1980.** Principles and procedures of statistics. McGraw-Hill, New York.

**Tenbrink, V. L., A. H. Hara, T. Y. Hata, B.K.S. Hu, and R. Kaneko. 1998.** The Berlese funnel, a tool for monitoring thrips on orchids. Insect Pests Leafl. IP-3. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI.

**Terry, L. I., and G. DeGrandi-Hoffman. 1988.** Monitoring western flower thrips (Thysanoptera: Thripidae) in "Granny Smith" apple blossom clusters. Can. Entomol. 120: 1003–1016.

*Received for publication 11 May 2001; accepted 15 November 2001.*